PB-233 739

MEASUREMENT OF ENTRAINED LIQUID LEVELS IN EFFLUENT GASES FROM SCRUBBER DEMISTERS

L. D. Johnson, et al

National Environmental Research Center
Research Triangle Park, North Carolina

June 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

i

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RE PB 233 739
EPA-650/2-74-050		

4. TITLE AND SUBTITLE	5. REPORT DATE
Measurement of Entrained Liquid Levels in Effluent Gases from Scrubber Demisters	June 1974
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
L. D. Johnson and R. M. Statnick	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Process Measurements Section Particulate and Chemical Processes Branch Control Systems Laboratory	1AB013; ROAP 21ACY-44
	11. CONTRACT/GRANT NO.
	NA
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development NERC-RTP, Control Systems Laboratory Research Triangle Park, NC 27711	In-house; final
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

The report gives results of the development and field-testing of a method for determining entrained liquid levels in gases leaving scrubber demisters, based on the use of a soluble ion as a tracer. Trial measurements were made at two separate alkali scrubbing test facilities located at power plant sites. All results, both experimental and calculated, were reasonable and self-consistent. Agreement with independent estimates and practical experience was good.

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. Department of Commerce
Springfield VA 22151

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Air Pollution Control	13B
Demisters	Stationary Sources	13A
Scrubbers		07A
Measurement		14B
Moisture Content		07D
Entrainment		

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
Unlimited	Unclassified	19
	20. SECURITY CLASS *(This page)*	22. PRICE
	Unclassified	$3.00-1.45

EPA Form 2220-1 (9-73)

EPA-650/2-74-050

MEASUREMENT OF ENTRAINED LIQUID LEVELS IN EFFLUENT GASES FROM SCRUBBER DEMISTERS

by

L. D. Johnson and R. M. Statnick
Control Systems Laboratory
Process Measurements Section
Particulate and Chemical Processes Branch
Research Triangle Park, North Carolina

ROAP No. 21ACY-44
Program Element No. 1AB013

Prepared for

NATIONAL ENVIRONMENTAL RESEARCH CENTER
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711

June 1974

This report has been reviewed by the Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

CONTENTS

	Page
Acknowledgements	iv
Introduction	1
Theory	1
Experimental Work	2
Calculations	3
Results	6
Discussion	10
Conclusion	13
References	13

LIST OF FIGURES

Fig.	Title	Page
1	Effect of Stack Flow Rate on Mist Carry-over	8

LIST OF TABLES

Table	Title	Page
I	Input and Output Variables for Calculation of Entrainment	4
II	Equations for Calculation of Entrainment	5
III	Experimental Mist Entrainment Results	6

ACKNOWLEDGMENTS

The assistance of F. E. Briden and R. S. Steiber of EPA and Gary Thom of Zurn Industries is gratefully acknowledged.

INTRODUCTION

Wet scrubbers have been widely used for a number of years for removal of pollutants from stack effluents. A large number of different designs are possible, and many are in practical use today. Most, if not all, of these devices produce entrained scrubber liquor droplets in the air stream, and many require demister devices for removal of this potential chemical pollution prior to discharge. Although the quantitative determination of entrained liquid levels in gases leaving scrubber demisters has long been recognized as an important goal, no satisfactory and convenient method has been available. This report describes the theory and testing of a method based on the use of an existing soluble ion as a tracer agent.

THEORY

The theory behind the present determination is fairly simple, and is typical of most "tracer" type experiments. In this case, the assumption is made that the only major source of sodium ion in the system is the scrubber feed liquor. If this is true, then only entrainment of scrubber liquor can cause sodium ion above the demister. If one measures the amount of sodium ion in a given volume of stack gas, it is then possible to calculate the total amount of sodium ion passing through the stack. The concentration of sodium ion in the feed liquor to the scrubbers is easily determined, and is usually constant for a given set of process controls. Since this concentration specifies the amount of liquor volume associated

with a given amount of sodium ion, it may be readily used along with the sodium ion level in the stack to calculate entrained liquor carry-over. Although a constant sodium level in the liquor is preferable, an average value may be used when this concentration varies. Any major source of sodium other than the liquor would invalidate the use of sodium as the tracer, but not the concept of the test. In such a case, it might be necessary to add another element or compound to act as the tracer. The tracer method, of course, is quite general, and therefore is not limited to use of sodium ion. Any convenient soluble ion may be used, and may be analyzed by any analytical method available.

EXPERIMENTAL WORK

The procedure described below was field tested at two locations. The first was a large coal-fired power generating plant, which utilized a turbulent contact absorber unit. This unit was designed to employ a limestone slurry as the scrubbing medium, but was temporarily charged with sodium carbonate solution. The stack was equipped with a chevron type demister device, and an oil-fired flue gas reheater.

The second installation was an oil-fired municipal power generating plant equipped with an inspiration scrubber and gull wing demister. The unit was being tested with sea water as the scrubber solution, but was slated to eventually use a coral marl slurry.

Sampling was accomplished by a dry filtration technique similar to that described in the Federal Register.[1] Basically, the equipment consists of probe, filter, impingers, pump, dry test meter, pitot tube, and inclined manometers. Stack sampling procedures also conformed to Federal Register requirements. During the sample run, the probe, cyclone, and filter holder were all maintained at 250°F.* Two Millipore type HAWP 14350 filters were used sequentially in the same holder. All pertinent instrumental parameters were recorded during the test, and all essential process data were obtained as soon as practical. For a listing of required information, see Table I.

After collection of the sample and cooling of the equipment, the probe and cyclone were rinsed with distilled water, and the filters were soaked overnight in distilled water. Volumes were determined by graduated cylinders for each of the resultant liquid samples, and they were analyzed for sodium content by atomic absorption spectroscopy.[2] Three samples were produced in all: liquid from impingers; wash water from probe, cyclone and filters; and blank distilled water. Water soluble sodium blanks were also determined on unused filters.

CALCULATIONS

Calculations were performed by computer, but were based on equations given in the Federal Register.[1] Input was flexible enough

---

* Although EPA policy is to use metric units, certain non-metric units are used here for convenience. The following factors can be used to convert to metric units: $m^3 = 0.0283 \times ft^3$; $mm = 25.4 \times in.$; $m^2 = 0.0929 \times ft^2$; $m^3/min = 0.0283 \times ft^3/min$; and $°C = 5/9 (°F - 32)$.

Table I. INPUT AND OUTPUT VARIABLES FOR CALCULATION OF ENTRAINMENT

Input

VM - sample through dry gas meter, ft^3

PB - barometric pressure at orifice, in. Hg

DH - pressure drop across orifice, in. water

TMF - gas meter temperature, °F

{ TIF - flue gas temperature, °F
or
BWO - volume fraction of water vapor in gas stream

VIC - total volume of liquid collected in impingers and silica gel, ml

{ QI - volumetric flow rate at stack conditions, ft^3/min
or
DP - average pitot pressure drop, in. H_2O, and
A - stack area, ft^2

CI - sodium concentration in impingers, mg/l

VA - volume of liquid in impingers after run, ml

VB - volume of liquid in impingers before run, ml

CF - sodium concentration in filter and probe wash, mg/l

VF - volume of filter and probe wash, ml

CB - sodium concentration in blank, mg/l

CL - sodium concentration in liquor to scrubbers, mg/l

Output

VMS - sample volume, STP and dry, ft^3

QS - volumetric flow rate in stack, STP and dry, ft^3/min

NAI, NAF, NAT - sodium in impingers, filters and probe, and total, mg

VL, VLG - entrained scrubber liquid past demisters, in ml/min and gal/hr respectively

to accept data in several forms. A list of input and output variables, along with their designations, is given in Table II. Equations used are given in Table II.

Table II. EQUATIONS FOR CALCULATION OF ENTRAINMENT

$$VMS = \frac{17.71VM\ (PB + \frac{DH}{13.6})}{TMF + 460}$$

$$BWO = \frac{0.0474V1C}{VMS + 0.0474V1C}$$

either $$VS^{*} = Kp\ Cp\ \sqrt{DP}\ \sqrt{\frac{TS}{(PSXMS)}}$$

$$= \frac{(85.48)\ (.85)}{\sqrt{29}}\ \sqrt{\frac{DP\ (T1F + 460)}{PB}}$$

$$= 13.48\ \sqrt{\frac{DP\ (T1F + 460)}{PB}}$$

and

$$QS = 60(1-BWO)(VS)(A)\left(\frac{530}{T1F + 460}\right)\left(\frac{PB}{29.92}\right)$$

$$= 1063(A)(VS)(PB)(1-BWO) \div (T1F + 460)$$

or $$QS = 17.71Q1(PB)(1-BWO) \div (T1F + 460)$$

$$NAI = (CI(VA) - CB(VB)) \div 1000$$
$$NAF = (CF(VF) - CB(VF)) \div 1000$$
$$NAT = NAI + NAF$$
$$VL = 1000\ NAT\ (QS) \div (VMS(CL))$$
$$VLG = 60VL \div 3790$$

* VS, Kp, Cp, TS, PS, and MS are defined in Reference (1).

RESULTS

Table III gives results in terms of both milliliters of entrained liquid per minute and gallons of entrained liquid per hour. These entrainment values agreed within 10% of figures obtained by plant engineers from lengthy material balances and estimation. The volumetric flow rate in the stack was also included since this important value may be used directly to put the entrainment quantities into perspective, or indirectly to calculate face velocities or other useful operational variables. Corrected sample volume and various sodium concentrations were also output from the equations used, but were not general enough in interest to warrant their inclusion in the present data table. The list of output variables contains further information on the result designations.

Table III. EXPERIMENTAL MIST ENTRAINMENT RESULTS

Test	VL, ml/min	VLG, gal/hr	QS, ft /min	PD, in. H_2O
SH1	14	0.22	21,000	-
KW1	1,200	19	37,000	8
KW2	4,600	73	57,000	8
KW3	2,000	31	26,000	8
KW4	3,800	60	35,000	12
KW5	26,000	400	57,000	12
KW6	17,000	260	56,000	12

The results from the second installation, all designated KW, were further related to the pressure differential across the intake tube for the scrubber, an important variable designated as PD. When gal/hr entrained scrubber liquor was plotted against volumetric flow rate in stacks, the curves shown in Figure 1 were obtained. These are very similar in nature to curves obtained by the scrubber manufacturer on pilot plant equipment.

In contrast to the heavy entrainment levels found in the KW series, the SH location showed only 14 ml of liquor loss per minute. In view of the large flue gas and scrubber liquor volumes involved in this operation, the low value indicated very efficient operation of the demisters. The figure is quite reasonable, however, since the scrubber was temporarily without its "ping-pong ball" agitators, a fairly low flow rate of flue gas prevailed, and operating conditions during the test were very nearly ideal for effective operation of the devices.

An effect, which initially caused some concern, was observed at the SH locations. Even though the tracer method indicated that a total of only 14 ml of mist per minute was carried up the stack (and therefore that only about 0.1 ml should be collected by the sampling train during the course of the test), 100 ml of water in addition to the initial 200 ml was recovered from the impingers.

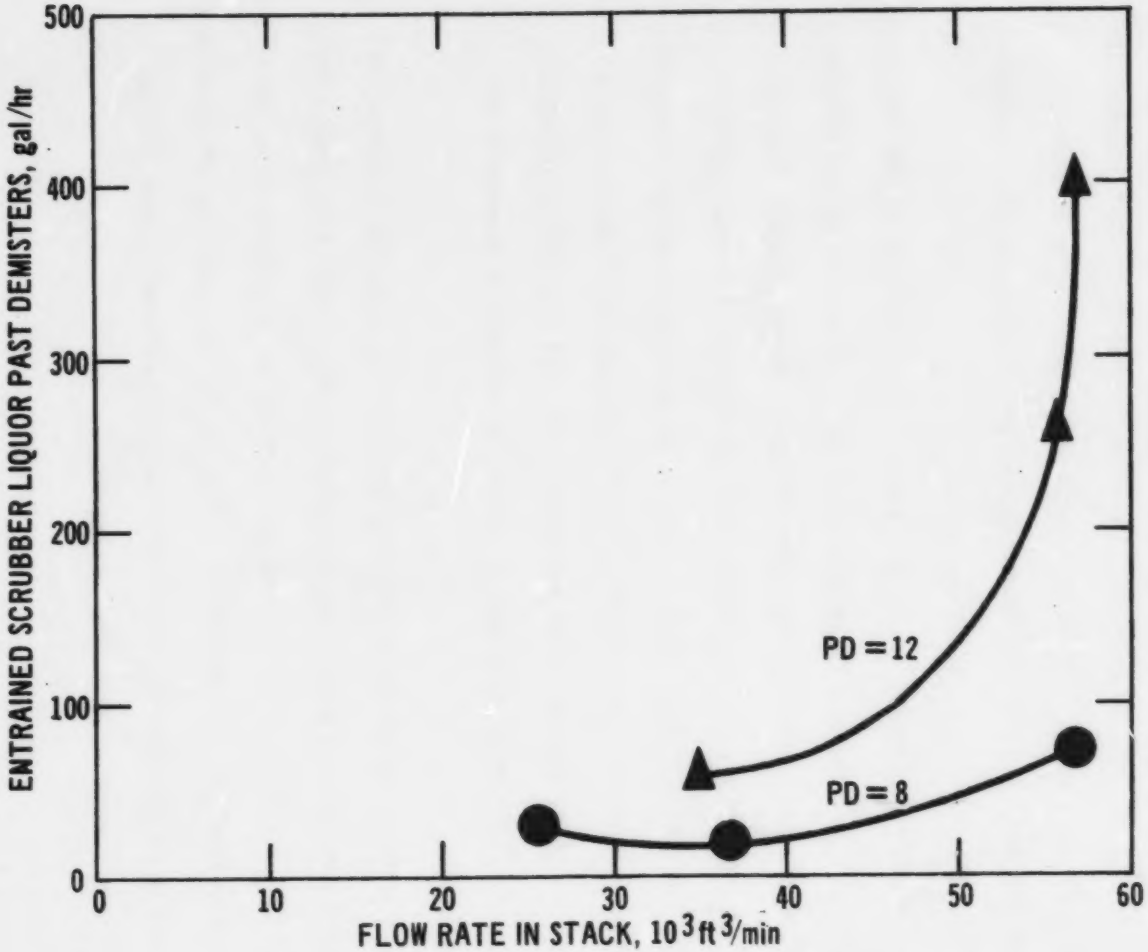

Figure 1. Effect of stack flow rate on mist carry-over.

A series of calculations was made in order to account for this difference, and the results are useful beyond this isolated sample. They show the relative importance of various moisture contributions to the flue gas, and may act as a guide when making material balances or corrections such as those mentioned in the discussion section.

The sources of water were: physical entrainment of scrubber liquor, trace amounts of water in the fuel oil to the reheater, combustion products from the burning of the oil, evaporated scrubber liquor, and water from the boiler gases.

As mentioned previously, entrainment accounts for only 0.1 ml of the total 100 ml; since typical water content of No. 2 fuel oil is only a trace (0.1% is the maximum for ASTM requirements[3]), only about 0.01 ml of the impinger catch would be likely to come directly from the oil. A typical value for moisture formation from burning No. 2 fuel oil was obtained by means of tables and formulas from "Combustion Engineering".[3] An estimate of the amount of water contributed to the impingers by this mechanism was then easily calculated. Only 9 ml of the total 100 ml was computed to have come from combustion of the fuel oil.

Even though water is added separately by the boiler gases and evaporation of scrubber liquor, the flue gas leaving the scrubber will normally be saturated regardless of its moisture content upon leaving the boiler. Therefore, it may often be convenient to treat the two sources as one. In this case, for the sake of completeness, the boiler gas moisture content was also calculated separately. This moisture level is somewhat variable, but a typical value is

71g/m^3 at a scrubber entrance temperature of 300°F. Since it requires only 60g/m^3 of water to saturate the gas at its 110°F scrubber exit temperature, the boiler gas typically provides slightly more than enough for this purpose. Boiler gas with moisture content below 60g/m^3 is not especially unusual either, however, and in this case the scrubber provides the extra water necessary for saturation.

It was reasonable to assume that the flue gas was saturated with moisture at its exit temperature of 110°F. Based on absolute humidity figures from Lange,[4] it was calculated that it was possible to condense 187 ml of water from the sample simply by cooling the saturated gas from 110°F to 40°F. It was readily apparent that this boiler and scrubber humidification/condensation mechanism for contribution of water to the impingers was the dominant one, and far outweighed the other three.

DISCUSSION

Since the method described herein for determination of mist entrainment is an indirect one, it might be beneficial to discuss more direct methods. The obvious approach to a problem, if workable at all, is often the best.

The most direct and obvious way to measure mist carry-over past a demister device is to simply catch the liquid and measure it. This, however, requires a sample port immediately after the demister, and that all collection equipment be at the same temperature as the stack and demister.

The location of the sample port would be especially critical, in this case, since an attempt would be made to collect the entrained mist droplets in a liquid state, and to avoid condensing and capturing any of the humidity moisture at the same time. Any heating or cooling, even from passage through the stack, would cause evaporation or condensation and would invalidate the test. Evaporation and condensation would not affect the tracer technique since the quantity of sodium ion would be unchanged by these events.

The direct procedure, like the tracer method and the semidirect method discussed below, would normally require traversing the stack and isokinetic collection to insure a representative sample. In the likely event that the flue gas temperatures at each of the traverse points was not identical, it would be necessary to change the temperature of all the sampling and collection equipment to be isothermal with the gas at each point. Worse yet, the liquid collected at each point would have to be removed from the equipment before the temperature change in order to avoid condensation or evaporation. The result would be a number of liquid samples whose weight would need to be combined to obtain the final result.

Difficulties with this direct approach are readily apparent. A sample port may not be available immediately after the demister, and it may be physically or economically impossible to construct one. It would be especially difficult in most cases to match the stack temperature throughout the entire sampling period.

Another possible route to entrainment determination is to condense all water in the flue gas sample, either weigh or measure volume, assume saturation, from the flue gas temperature calculate the amount of water present due to saturation at that temperature, subtract this amount from the total water condensed, and call the difference entrained mist. A more refined calculation would need to consider density differences between the saturation water and the entrained liquor. This procedure would be most effective if sampling was immediately after the demister, but could be carried out farther up the flue with decreased accuracy due to reheaters, etc.

Both of the above methods may probably be made to work in certain specific cases. In nearly all practical situations, however, the tracer method will prove to be far easier, more economical, more readily applicable, and probably more accurate.

It should be mentioned that the filters used throughout the present work were somewhat embrittled by heat and moisture combined. This type of filter is composed of cellulose esters, which doubtless undergo hydrolysis reactions under the conditions mentioned. Filters of the Millipore "Solvinert" series are said to be more stable, and should be somewhat more satisfactory. Glass fiber filter mats should be satisfactory provided the sodium blank from these is consistent enough. Teflon filter mats are also available commercially, and might prove useful for this application.

CONCLUSION

Based on the tests presented, the method discussed above appears to be sound for the determination of entrained scrubber liquor carried past demisters. All results, both experimental and calculated, are reasonable and self-consistent.

REFERENCES

1. EPA, Standards of Performance for New Stationary Sources, Federal Register 36, No. 247, Part II, December 23, 1971.
2. Perkin-Elmer Corporation, "Analytical Methods for Atomic Absorption Spectrophotometry," Norwalk, Connecticut, 1968.
3. Fryling, G. R., editor, "Combustion Engineering," Combustion Engineering, Inc., New York, 1966, pp. 14-14 and 21-13.
4. Lange, N. A., "Lange's Handbook of Chemistry," 10th Edition, McGraw Hill, New York, 1967, pp. 1424.